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EVALUATION OF RIVER DISCHARGES, KEYSTONE RESERVOIR - ARKANSAS RIVER, OKLAHOMA

Public Health Service
Dallas, Texas

December 1959

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PB 228 355

EVALUATION OF RIVER DISCHARGES

KEYSTONE RESERVOIR - ARKANSAS RIVER

OKLAHOMA

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service, Region VII
Dallas, Texas

In Cooperation with the

DEPARTMENT OF THE ARMY
U. S. Army Engineer District - Tulsa, Oklahoma

DECEMBER 1959

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INTRODUCTION

In a letter dated February 18, 1959, the District Engineer, U. S. Army Engineer District, Tulsa, requested the Public Health Service, Region VII Office, Dallas, Texas, to evaluate low flow regulation benefits attributable to the Keystone Reservoir Project on the Arkansas River in alleviating downstream pollution and providing supplemental water supply. At a meeting in Dallas in June 1959, and confirmed in a letter dated June 19, 1959, the Tulsa District requested the following additional information.

a. Present pollution conditions (damages) based on the various experienced minimum stream flows at Tulsa.
b. Pollution damages or benefits for a range of stream flows verying from the minimum experienced flow up to the maximum flow required for complete pollution abatement
c. Unit value for water supply that may be provided in the Keystone Reservoir.

This study was made in accordance with the provisions of the Memorandum of Agreement dated November 4, 1958, between the Department of the Army and the Department of Health, Education, and Welfare under which the Public Health Service is to provide assistance to the Corps of Engineers in implementing the Water Supply Act of 1958.

Benefits attributable to releases from the proposed Keystone Reservoir have been estimated previously by the Public Health Service and were included in a letter dated May 15, 1952, to the District Engineer, Tulsa District, Corps of Engineers. In the fall of the same year the Public Health Service made a stream survey of the Arkansas River from Sand Springs to Webbers Falls, Oklahoma, as part of a comprehensive study of the Arkansas, White and Red River Basins. The primary object of this survey was to obtain data on river water quality for the prupose of determining the pollutional effects of municipal and industrial waste discharges to this reach of the Arkansas River. The results of this survey were included in a report entitled, Arkansas-White-Red-Field Studies, dated August, 1953.

After reviewing the above two reports, it was considered necessary to bring information up to date on waste loadings from both municipal and industrial sources. A field study was made in May 1959 during which officials of municipalities and industries were interviewed to obtain information concerning waste discharges and water supplies. Current data were obtained for Sand Springs, Tulsa, Bixby, Jenks, and Haskell, Oklahoma.

The following persons facilitated the completion of the field investigation through their assistance and cooperation and are gratefully acknowledged:

1. Mr. Harold Malone, Director, Division of Sanitary Engineering, Oklahoma State Health Department, Oklahoma City

2. Mr. Francis Borelli, Executive Director, Oklahoma Water Resources Board, Oklahoma City

3. Mr. Ted Williamson, Engineer, Oklahoma State Health Department, Oklahoma City

4. Mr. Clyde B. Eller, Sanitary Engineer, Tulsa City-County Health Department, Tulsa

5. Mr. A. B. Jewell, Superintendent of Water and Sewage, Tulsa

6. Mr. Charles Holden, Superintendent of Plants, Tulsa

7. Mr. Thomas Everett, City of Tulsa

8. Representatives of the various industrial firms studied.

SUMMARY AND CONCLUSIONS

1. The Arkansas River in the vicinity of the Keystone Dam site is too highly mineralized to be useful for municipal and industrial purposes. The river can be used as a cooling water supply for electric power generating plants because equipment required for heat transfer purposes is also corrosion resistant. Based on municipal water as the most economical alternate, the value of Arkansas River water as a cooling water supply for electric power generating plants is estimated to be 5.3 cents per thousand gallons.

2. At the present time and in the foreseeable future the major use of the Arkansas River below the Keystone Dam site is for the receiving of wastes.

3. The greatest pollution abatement problem affected by discharge regulation from the Keystone Reservoir is in the Tulsa-Sand Springs area.

4. In 1965, the completion date for the Keystone Reservoir project, the Arkansas River will be receiving the primary treated wastes of 165,000 people in Tulsa plus industrial wastes equivalent to a population of 92,000 and the secondary treated wastes from 10,000 people in the Sand Springs area.

5. Tulsa is expected to begin treating its municipal wastes discharging to the Arkansas River to remove 85 percent of the biochemical oxygen demand within 25 years. Calculations in this report are based on the additional treatment beginning in the year 1975, at which time the

Arkansas River would be receiving the secondary treated wastes of 200,000 people in the Tulsa area and an additional organic load equivalent to 114,000 people from industry.

6. The proposed plan for navigation in the Arkansas River system calls for the construction of a series of locks and dams in the Verdigris River below Tulsa. With these installations, continued discharge of waste effluents to the Verdigris may be expected to create adverse water quality conditions.

7. It is probable that all waste effluents in the Tulsa area will be discharged to the Arkansas River in about 1990. At that time 85 percent treatment will probably be required for all wastes in the Tulsa area including the municipal wastes from the expected 730,000 inhabitants and industrial wastes equivalent to an additional population of 495,000.

8. Based on unregulated river discharge and natural temperature conditions, the annual tangible damage in 1965 due to the discharge of organic wastes to the Arkansas River from the Tulsa area is estimated to be $54,000. If no further treatment of wastes is provided, this damage would increase uniformly to a maximum of $96,000 in 1989. The damage would be $70,800 in 1974. If 85 percent treatment of municipal wastes begins in 1975, the damage would be lowered to $37,400 in 1975 and would then increase to $51,800 in 1989. In 1990, with the discharging of all wastes in the Tulsa

area to the Arkansas River and providing 85 percent treatment, the damage would be $58,800. These damages are shown graphically in Figure 1.

9. Regulated discharges required to prevent tangible damage to the river in excess of that occurring under unregulated discharge conditions, those required for complete pollution abatement, and the monetary value of providing the discharges for complete pollution abatement for 1965, 1974, and 1989 with primary treatment of municipal wastes at Tulsa are given in Table 1. These figures for 1975 and 1989 with 85 percent treatment of municipal wastes at Tulsa are given in Table 2. The figures for 1990 with 85 percent treatment of all wastes in the Tulsa area are given in Table 3.

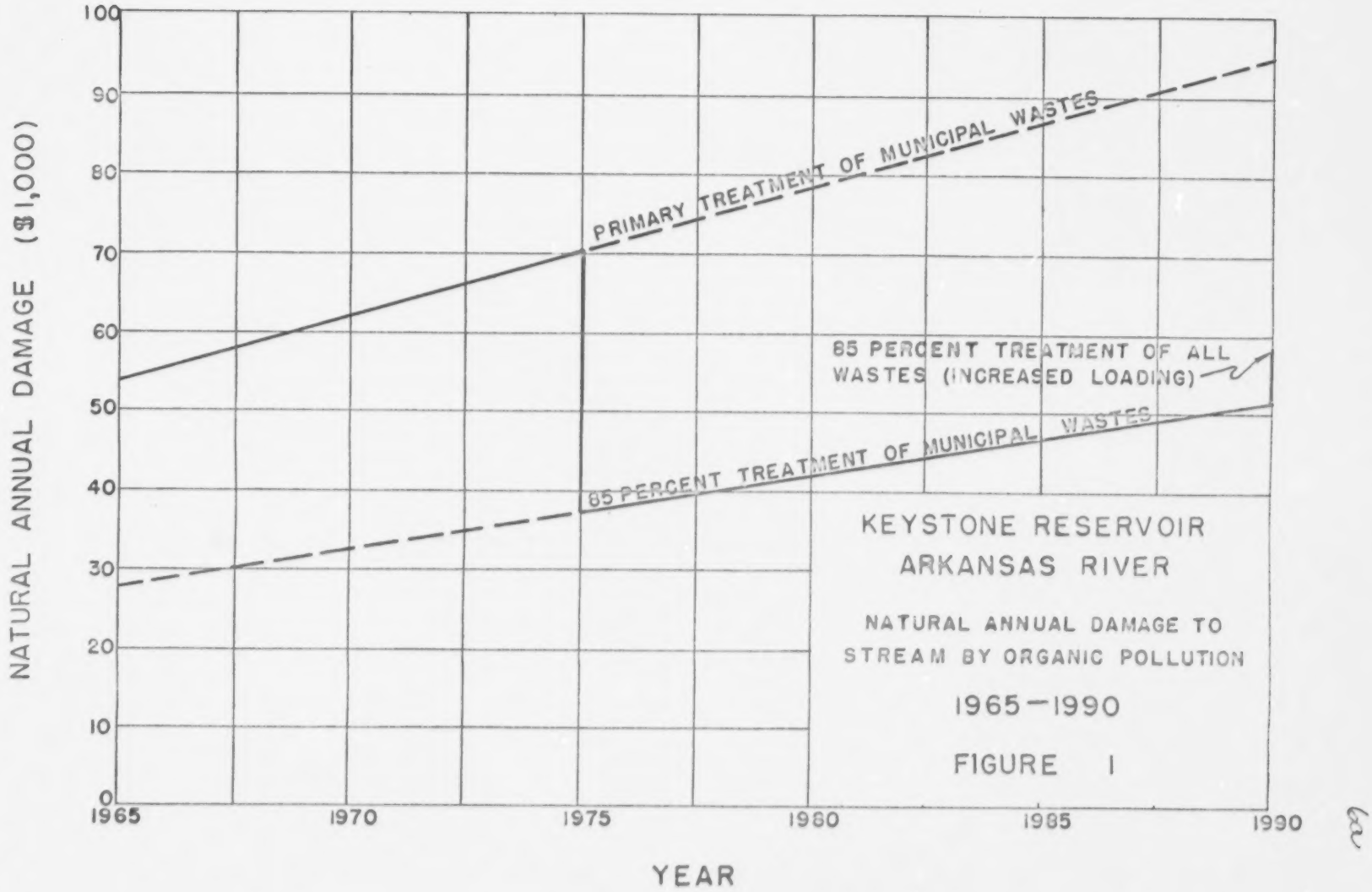

NATURAL ANNUAL DAMAGE ($1,000)
100
90
80
70
60
50
40
30
20
10
0
1965
1970
1975
1980
1985
1990
YEAR
PRIMARY TREATMENT OF MUNICIPAL WASTES
85 PERCENT TREATMENT OF ALL WASTES (INCREASED LOADING)
85 PERCENT TREATMENT OF MUNICIPAL WASTES
KEYSTONE RESERVOIR
ARKANSAS RIVER
NATURAL ANNUAL DAMAGE TO STREAM BY ORGANIC POLLUTION
1965—1990
FIGURE 1

Table 1. Values of Regulated Discharge With Primary Treatment of Municipal Wastes, 1965, 1974, and 1989

1965

Month	Discharge to Maintain Natural Conditions (Damages) (cfs)	Discharge to Maintain 4.0 ppm D. O. (No Damage) (cfs)	Percent of Month Augmentation Required	Value of No-Damage Discharge ($/year)
January	300	310	8.0	$ 3,800
February	315	320	3.0	1,100
March	345	350	4.0	1,900
April	410	430	5.0	2,300
May	540	540	1.9	0
June	640	640	1.9	0
July	675	700	4.2	1,300
August	600	730	22.0	9,600
September	465	580	26.0	13,600
October	415	460	19.0	10,000
November	330	345	10.5	5,200
December	300	315	10.5	5,400
		Total for the year	9.7%	$ 54,000

1974

January	370	395	11.5	5,500
February	395	410	5.0	2,300
March	435	445	6.0	2,800
April	515	540	6.5	3,100
May	660	665	1.5	300
June	770	785	2.8	600
July	785	845	5.8	2,700
August	700	880	26.0	11,700
September	560	710	29.0	15,600
October	500	575	23.0	12,000
November	410	440	14.0	7,100
December	370	405	15.0	7,300
		Total for the year	12.2%	$71,000

Table 1. (Cont'd)

1989

Month	Discharge to Maintain Natural Conditions (Damages) (cfs)	Discharge to Maintain 4.0 ppm D. O. (No Damage) (cfs)	Percent of Month Augmentation Required	Value of No-Damage Discharge ($/year)
January	475	520	17.0	8,000
February	520	545	9.5	4,000
March	565	590	9.2	4,200
April	670	705	9.0	4,200
May	840	850	2.5	800
June	960	1,000	4.3	1,400
July	950	1,060	8.5	4,800
August	850	1,110	31.0	14,900
September	700	910	34.0	18,600
October	625	750	28.0	15,000
November	525	580	20.0	10,000
December	475	535	20.0	10,100
		Total for the year	16.0%	$96,000

Table 2. Values of Regulated Discharges With 85 Percent Treatment of Municipal Wastes, 1975 - 1989

1975

Month	Discharge to Maintain Natural Conditions (Damages) (cfs)	Discharge to Maintain 4.0 ppm D. O. (No Damage) (cfs)	Percent of Month Augmentation Required	Value of No-Damage Discharge ($/year)
January	225	230	5.0	$ 2,300
February	240	240	1.5	0
March	260	265	2.5	1,100
April	325	330	3.4	1,500
May	400	400	0.5	0
June	470	470	1.0	0
July	495	500	2.3	700
August	460	525	16.5	6,900
September	370	425	21.0	10,900
October	320	350	15.0	7,400
November	250	260	6.0	3,100
December	225	230	7.0	3,500
		Total for the year	6.8%	$37,400

1989

January	285	290	7.3	3,500
February	310	310	2.7	0
March	345	350	4.1	1,800
April	420	425	4.8	2,200
May	510	510	0.8	0
June	595	600	1.7	500
July	630	640	3.7	1,200
August	570	576	21.0	9,300
September	460	545	25.0	13,400
October	410	450	19.0	9,700
November	330	345	10.4	5,000
December	290	300	10.0	5,200
		Total for the year	9.2%	$51,800

Table 3. Values of Regulated Discharges with 85 Percent Treatment of All Wastes in 1990

Month	Discharge to Maintain Natural Conditions (Damages) (cfs)	Discharge to Maintain 4.0 ppm D. O. (No Damages) (cfs)	Percent of Month Augmentation Required	Value of No-Damage Discharge ($/year)
January	265	275	6.8	$ 3,600
February	295	295	2.3	0
March	330	330	3.8	0
April	380	390	4.3	2,300
May	455	455	0.1	0
June	525	525	1.3	0
July	555	570	3.0	1,200
August	490	600	19.0	11,500
September	385	480	23.0	17,500
October	360	410	17.2	11,800
November	310	325	9.6	5,200
December	270	285	9.5	5,700
		Total for the year	8.3%	$ 58,800

10. The constant discharges maintained the entire year which would prevent tangible damage to the river beyond that occurring under unregulated discharge conditions are as follows:

	Constant Discharge (cfs)		
Year	Primary Treatment of Municipal Wastes	85 Percent Treatment of Municipal Wastes	85 Percent Treatment of All Wastes
1965	510	---	---
1974	600	---	---
1975	---	405	---
1989	740	505	---
1990	---	---	435

11. It should be noted that rapid and extreme variations in river discharges would cause severe, although intangible, damages to the river. Similarly, maintenance of constant discharges would provide substantial, yet intangible, benefits to the river.

12. The values of any discharges released during any given reservoir operation may be determined by the procedure presented in Appendix III.

DISCUSSION

The Keystone Dam site is located on the Arkansas River about ten miles upstream from the Tulsa-Sand Springs area in northeastern Oklahoma. The reach of the river considered in this study is from the Keystone Dam site to the confluence of the Verdigris River.

The water of the Arkansas River in the vicinity of the Keystone Dam site has limited uses. The high concentrations of chlorides, sulfates, and other minerals prevent its use for municipal water supply and greatly reduce its value for industrial use. The value of this water is further limited by the fact that an abundant supply of high quality water is available from other nearby sources. A survey of industries in the Tulsa area has revealed only one plant using water from the Arkansas River. The Tulsa station of the Public Service Company of Oklahoma uses this water for cooling purposes. However, the major use of the Arkansas River in the vicinity of the Keystone Dam site is for the receiving of municipal and industrial waste discharges.

The major sources of municipal and industrial wastes discharged to the Arkansas River below the Keystone Dam site are in the Tulsa-Sand Springs area. Here the City of Sand Springs discharges all of its sewage after secondary treatment and the City of Tulsa discharges a part of its sewage after primary treatment. (The remainder of Tulsa sewage is subjected to secondary treatment and is discharged into the Verdigris River Basin.) Including the separate wastes from a considerable number of industries, the total discharge of wastes

into the Arkansas River below Keystone Dam site (after the treatment indicated above) is equivalent to that from a population of 175,000.

Tulsa is expected to begin treating its municipal wastes discharging to the Arkansas River to remove 85 percent of biochemical oxygen demand within the next 25 years. Calculations in this report are based on the additional treatment beginning in 1975.

It is probable that all waste effluents in the entire Tulsa area will be diverted to the Arkansas River about 1990. This change is expected because the proposed plan for navigation in the Arkansas River system calls for the construction of a series of locks and dams in the Verdigris River below Tulsa. With these installations, continued discharge of waste effluents to the Verdigris River basin may be expected to create adverse water quality conditions. The discharging of all wastes to the Arkansas River will probably be accompanied by the provision of 85 percent treatment for all wastes.

An evaluation of river discharges has been made for several select years:

1965 - the year of completion of Keystone Dam

1974 - the year before Tulsa is expected to provide 85 percent treatment of municipal wastes discharged to the Arkansas River

1975 - the year Tulsa is expected to begin providing 85 percent treatment of municipal wastes discharged to the Arkansas River

1989 - the last year the Tulsa area is expected to discharge wastes into the Verdigris River basin

1990 - the year Tulsa is expected to divert all its wastes to the Arkansas River and provide 85 percent treatment for all wastes.

Projection beyond 1990 was not made because a recomputation of the evaluation of river discharges at a later date based upon actual waste loadings would be desirable.

Monetary values of river discharges are difficult to ascertain. The method of determining values used in the past was to compare the costs of various methods available that would result in the same conditions in the river. Accordingly, the value of augmented discharges was construed to be equivalent to the cost of the least expensive method of waste treatment that would give the same degree of damage control. The validy of this method presupposes that the alternative solution of discharging sewage of varying degrees of treatment is satisfactory. This policy has been changed. Due to the increasing use and reuse of water resources, higher standards of sewage treatment are considered desirable in most cases. This change in policy made it necessary to develop a new method of evaluating

damage control benefits of river discharge regulation. This method, described under "Method of Analysis," page 28 has been used in the evaluation of river discharges in the Arkansas River at Tulsa. In this method the values of regulated discharges were determined by comparing values ascribed to river conditions at regulated discharges with those ascribed to conditions which would exist under natural discharges. Dissolved oxygen concentration has been taken as the indicator of the condition of the river.

Benefits may in general be classified as either tangible or intangible. Tangible benefits are those which are capable of monetary measurement, while intangible benefits are not. The following discussion describes further benefits and damages which may be classified as intangible.

The benefit of maintaining biological equilibrium in the river would be substantial. The maintenance of constant discharges would have a stabilizing effect on the biota of the river. Many of these biota, which are essential to the assimilation of organic wastes in the river, become inactive when the dissolved oxygen is lowered and require some time for recovery. Other beneficial biota may be flushed away by high velocities during periods of rapidly increasing discharges. Fluctuating river levels create an undesirable environment for the biota due to dry conditions at low levels. Discharges which fluctuate rapidly over extreme ranges do not permit biota to be fully re-established. Even though these additional benefits and

damages are substantial, it is not possible to establish monetary values for them.

DESCRIPTION OF AREA

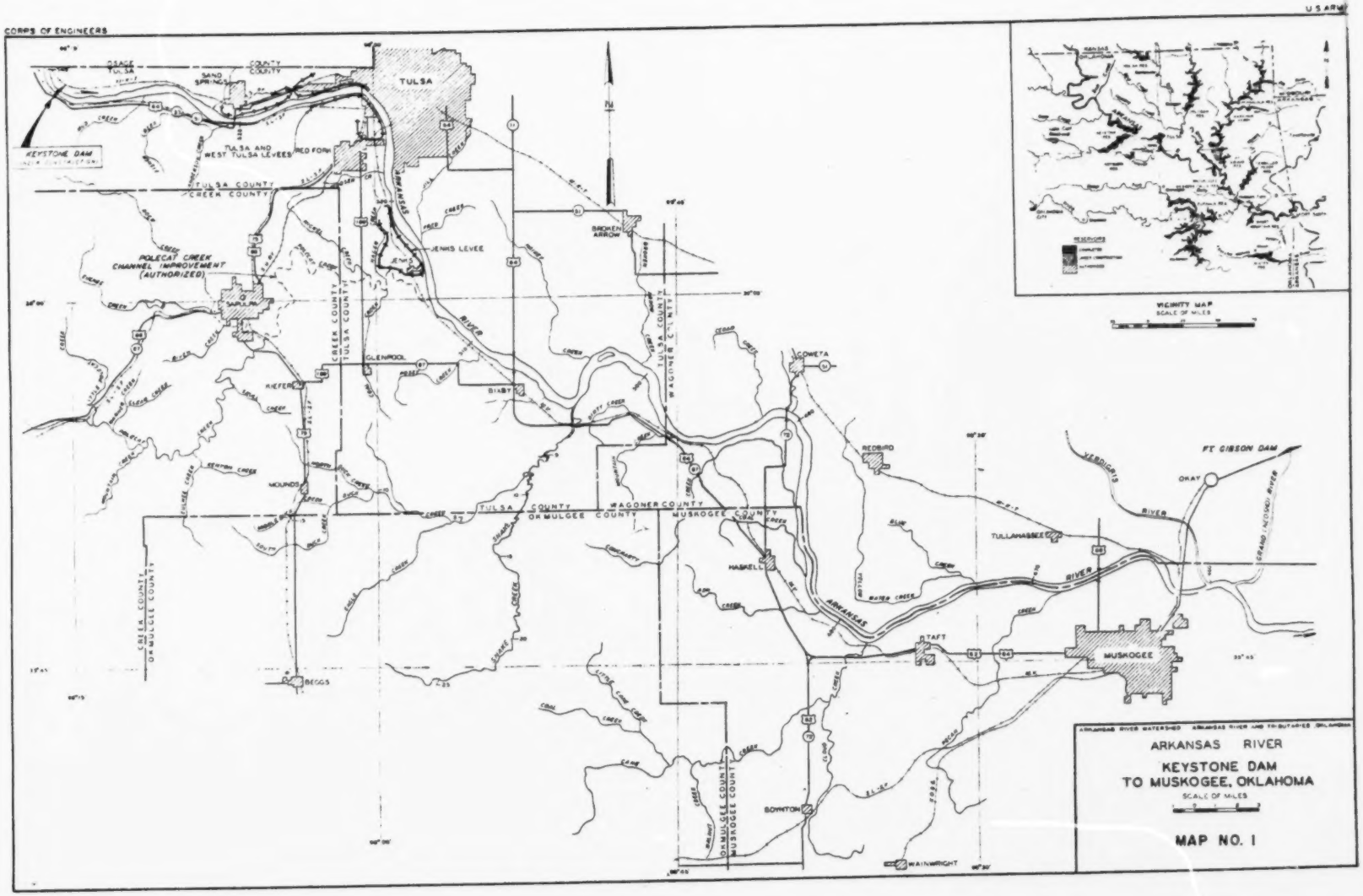
Geography

The Arkansas River between the Keystone Dam site and the confluence of the Verdigris River (a distance of 79 miles) flows in an east-southeasterly direction. The contributing drainage area above the Keystone Dam site is 61,965 square miles and that above the point of confluence of the Verdigris River is 63,304 square miles. The main tributaries to the Arkansas River in this reach are Polecat, Hackey, Snake, Concharty, Coal, Yellow Water, Pecan, Coody, and Sapinard Creeks. Map 1 shows the area in the vicinity of Keystone Reservoir.

The topography of the area under consideration is rolling prairie. The slope of the Arkansas River bed in this reach is about two feet per mile.

Economics

The principal industry in this region is the production and processing of petroleum products. Other industries of significance are metal fabrication and plating, chemical manufacturing, and meat packing. A large cotton textile mill and a steel plant are also located here. Much farming is done in this area--corn, small grains and forage being the principal crops. The raising of livestock is prevalent.


CORPS OF ENGINEERS
U.S. ARMY
TULSA
SAND SPRINGS
KEYSTONE DAM
TULSA AND WEST TULSA LEVEES
RED FORK
TULSA COUNTY
CREEK COUNTY
POLECAT CREEK CHANNEL IMPROVEMENT (AUTHORIZED)
JENKS LEVEE
BROKEN ARROW
SAPULPA
GLENPOOL
BIXBY
KIEFER
MOUNDS
BEGGS
OKMULGEE COUNTY
MUSKOGEE COUNTY
WAGONER COUNTY
COWETA
REDBIRD
TULLAHASSEE
HASKELL
STAFF
MUSKOGEE
FT GIBSON DAM
OKAY
VERDIGRIS RIVER
GRAND (NEOSHO) RIVER
ARKANSAS RIVER
BOWLEGS
WAINWRIGHT
VICINITY MAP
SCALE OF MILES
ARKANSAS RIVER WATERSHED ARKANSAS RIVER AND TRIBUTARIES OKLAHOMA
ARKANSAS RIVER
KEYSTONE DAM
TO MUSKOGEE, OKLAHOMA
SCALE OF MILES
MAP NO. 1

17a

Population

The growth of Tulsa in the past 20 years has been rapid. The 1940 population of Tulsa was 142,157 and by 1950 it had expanded to 180,586, an increase of 27 percent. During the same period the Tulsa metropolitan area grew from 193,363 to 248,658, a 28 percent increase. It appears that this area will continue to grow at a more rapid rate in the future, both in population and industry. This will, of course, result in an increase in waste loading to the Arkansas River.

WATER USES

The use of the Arkansas River for water supply at present is limited. The main sources of municipal and industrial water supply in the area are impoundments on tributaries of the Arkansas River--in most cases on tributaries considerable distances from the main stem of the Arkansas River. The current status of municipal water supply uses in the area of the Arkansas River under consideration is as follows:

Municipality	Source	Water Use (mgd)
Sand Springs	Shell Creek (tributary to Arkansas River)	1.0
Tulsa	Spavinaw Creek (tributary to Grand River)	43.8 (in 1957)
Jenks	Ground water	0.143
Bixby	Ground water	0.20
Haskell	Ground water	1.10*

* Includes a seasonal cannery with a water use of 0.936 mgd.

Ground water in the Arkansas River alluvium in the area is utilized for industrial and domestic purposes in the Tulsa-Sand Springs area and for irrigation and water flooding use in connection with oil production between Tulsa and Muskogee.

The communities of Bixby, Jenks, and Haskell also obtain their municipal water supply from the ground water alluvium of the river. According to the information obtained from these users, both the quantity and quality of the alluvial waters vary with the flow in the Arkansas River. Even though considerable use is made of the ground water in the river alluvium downstream from the dam site, detailed consideration of the monetary benefits or damages to these uses from discharge regulation was deemed beyond the scope of this report.

There are 2,000 acres in the river basin in Tulsa County presently under irrigation. It is estimated that another 2,000 acres are under irrigation from the Tulsa County line to the City of Muskogee. Water for irrigation is obtained largely from the ground water alluvium.

Use of the alluvial water is also being made for water flooding for oil production in the vicinity of Jenks. It is estimated that by 1965 this use will double to about 14.7 million gallons per day.

The principal use of this reach of the Arkansas River at the present time is for municipal and industrial waste disposal. Proper regulation of discharges in the river would improve its water quality with a probable increase in the river's use for fishing and recreation.

Most industries in the area obtain their water supply, for both processing and cooling, from the communities in which they are located. The highly industrialized area to the west of Tulsa is served by that city. A stream power plant in Tulsa uses the Arkansas River for cooling purposes. A once-through use of river water serves about ten percent of the power capacity, while cooling towers for the remainder of the power capacity use make-up water from the river. The total present use is about 75 cubic feet per second at the power plant.

Water Quality

The poor chemical quality of the waters of the main stem of the Arkansas River in this reach limits its use as a potable or industrial water source. The average concentration of total dissolved solids of the Arkansas River at Tulsa for the 11 year period ending in 1957 was 3,790 ppm. For this same period, the averages of sulfates and chlorides at Tulsa were 198 ppm and 1,440 ppm, respectively. During this same period the monthly average flow of the river at Tulsa ranged from a minimum 89.5 cfs in 1956 to a maximum of 61,100 cfs in 1957.1/

1/ Public Health Service, Data Report, Arkansas-Red River Basins, Water Quality Conservation Project, January 1959.

Data from the U. S. Geological Survey water quality station near Tulsa show that in a typical water year total hardness will vary from 400 to 800 ppm with non-carbonate hardness of 300 to 400 ppm. These concentrations occurred at discharges of about 800 to 1000 cfs.

The U. S. Public Health Service standards for drinking water established in 1946 state that the concentration of total solids should not exceed 500 ppm for a water of good chemical quality; and, if such water is not available, a total solids content of 1,000 ppm may be permitted. The standards further state that concentrations of sulfates and chlorides should not exceed 250 ppm each. A maximum of 250 ppm sulfate is suggested; the significance of the sulfate being that it adds to the laxative effect of highly mineralized waters. Comparing these standards with the averages given above, it can be seen that the quality of the Arkansas River at Tulsa would be unsuitable for drinking water from the standpoint of total solids and chlorides.

The highly mineralized water of the Arkansas River in the vicinity of the Keystone Dam site is also unsuitable for most industrial uses. If industry were to use the water as a process supply, the water treatment and equipment costs would be quite high. The use of the water as an industrial cooling water supply is greatly limited because of the high cost of construction materials required in the heat exchangers.

The conditions of extremely high temperatures and pressures in a stream power plant require the use of expensive materials of construction to provide for efficient heat transfer, and corrosion resistance

is an added feature of the material which makes possible the using of brackish water without excessive repair and maintenance costs. However, the conditions of most industrial cooling processes are such that expensive corrosion resistant materials are not required if the cooling water is not highly mineralized. The use of treated sewage has been considered by industry in the Tulsa area for cooling water in preference to the use of Arkansas River water as an alternate to municipal water. A more detailed discussion of factors limiting the industrial use of Arkansas River water is presented in Appendix I.

Value of Water Supply

Based on a comparison of the use of Arkansas River water to the use of municipal water for steam power plant cooling purposes, the value of Arkansas River water below Keystone Dam site for that purpose is estimated to be 5.3 cents per thousand gallons. This value is based entirely on operating costs since an increase in construction cost due to the corriveness of the highly mineralized water is negligible in the case of a steam power plant.*

The value of the Arkansas River in the vicinity of the Keystone Dam site for other industrial uses is considered to be very small. Only a very lengthy and detailed engineering study of specific industrial plants would permit the determination of this small value. Because of the limits of the present study, no definite value is given for this use.

*Calculations based on data presented in a letter from the Public Service Company of Oklahoma, dated November 17, 1959.

In view of the fact that other adequate sources are available in the area, the Arkansas River has no value for municipal water supply in the foreseeable future. The value of alluvial waters that may be affected by river levels have not been considered in this study.

SOURCES OF POLLUTION

Estimated organic waste loadings into the main stem of the Arkansas River from Keystone Dam site to the confluence of the Verdigris River in 1965 are as follows:

Location	Type of Waste	Estimated Population Equivalent Discharge (1965)
Sand Springs	Municipal	1,500
	Industrial *	16,500
Tulsa	Municipal	97,000
	Industrial *	76,000
Jenks	Municipal	1,800
	Industrial *	-
Bixby	Municipal	2,000
	Industrial *	-
Haskell	Municipal	3,200
	Industrial *	5,100

Organic pollution loads other than those from the Tulsa-Sand Springs area are found to be small when comparing their effects on the Arkansas River. Only those loads from the Tulsa-Sand Springs area have been considered in detail in this report. Predicted organic pollution loads discharging to the Arkansas River from the Tulsa-Sand Springs area are summarized as follows: (See discussion for explanation of dates.)

---

* Those industries which have separate discharges to the Arkansas River.

Date	Organic Pollution load (Population Equivalents) to Arkansas River		
	Primary Treatment of Municipal Wastes	85 Percent Treatment of Municipal Wastes	85 Percent Treatment of All Wastes
1965	191,000	--	--
1974	243,000	--	--
1975	--	141,000	--
1989	320,000	195,000	--
1990	--	--	184,000

The populations predicted to be served by sewerage systems discharging to the Arkansas River in the Tulsa area are as follows:

1965 - - - - - - 175,000 (including 10,000 in Sand Springs)

1974 & 1975 - - 200,000

1989 & 1990 - - 730,000

The discharge of highly mineralized wastes from both natrual and man-made sources is the major pollution problem affecting the quality of the Arkansas River above the Tulsa-Sand Springs area. Data currently being obtained as part of the "Arkansas-Red River Water Quality Conservation Study" being conducted by the Public Health Service have pinpointed many of these sources of pollution and studies are currently under way by Public Health Service to determine the feasibility of reducing, if not entirely eliminating, both natural and man-made pollutants.

RESERVOIR DATA

The Keystone Reservoir project is a major unit in the multiple-purpose plan for the development of the Arkansas River Basin. It is designed for flood control, navigation, power and water supply. Facilities for future power are provided in the initial development of the project. The reservoir is a key unit in the development of the navigation plan for the Arkansas River in that it will control sedimentation and aid in flow regulation. The multiple-purpose plan provides for a navigable waterway from Catoosa, Oklahoma (15 miles east of Tulsa), to the Mississippi River.

Principal features of the reservoir are shown below.

Keystone Reservoir

Storage Allocations

Allocation	Storage (acre-feet)
Flood control (initial)	1,414,000
Conservation and sediment reserve (initial)	465,000 *
Total (initial)	1,879,000

Pool Elevations

Pool	Elevations (feet above msl)
Conservation and sediment reserve	714.5
Flood control	754.0

* Includes 50,000 acre-feet for water supply.

DETERMINATION OF BENEFITS

The initial phase of the present study consisted of reviewing the two previous Public Health Service reports, mentioned in the Introduction (Items 1 and 2 in the Bibliogrpahy), and other reports and publications listed in the Bibliography. After reviewing these reports, it was considered necessary to bring information up to date on waste loadings from both municipal and industrial sources. A field study was made in May 1959 by engineers of the Public Health Service with the cooperation of the Oklahoma State Health Department, Oklahoma Water Resources Board, Tulsa City-County Health Department, and the City of Tulsa. During the study officials of municipalities and industries from Sand Springs to Haskell, Oklahoma, were interviewed to obtain information concerning waste discharges and water supplies. From data obtained a total organic waste loading to the river under present conditions was determined.

Method of Analysis

The values of discharges in the Arkansas River as regulated by the proposed Keystone Dam were determined on the basis of the following two premises:

1. The maximum damage to the river occurs when the dissolved oxygen concentration is reduced to zero, while no damage occurs when the dissolved oxygen concentration is four parts per million.

2. The value of protecting the stream from damage is equivalent to the cost of treating wastes potentially discharged to the river to a reasonably high degree, i.e., 85 percent removal of biochemical oxygen demand (B.O.D.).

In this study intermediate damages were assumed to vary directly with the dissolved oxygen deficit.

The dissolved oxygen concentrations occurring at the discharges under consideration were determined by the use of the oxygen-sag equation.[2/] Data on B.O.D. loadings were obtained from the municipalities and industries discharging wastes to the Arkansas River from the dam site to the confluence of the Verdigris River, Oklahoma. The sizes of waste treatment plants for 85 percent removal of B.O.D. were based on predicted population; and from these sizes, the plant costs were calculated.

Since temperatures in the Arkansas River vary considerably within any year, and since allowable B.O.D. loadings vary with the temperature of the receiving stream, water discharges required to maintain various dissolved oxygen concentrations were computed for each month of the year. Discharge frequency curves were also developed for each month of the year, and the percent of time damage occurs at various rates was deter-

2/ Streeter, H. W. and Phelps, E. B., A Study of the Pollution and Natural Purification of the Ohio River. III. Factors Concerned in the Phenomena of Oxidation and Reaeration, U. S. Public Health Service, Washington D. C., February 1925 (Public Health Bulletin No. 146).

mined by a comparison of natural discharges to discharges required to avoid damage. The summation of monthly damages then gave the annual damage caused by natural discharges. Regulated discharges, which would result in the same annual damage as occurs under natural conditions, were computed and called status quo discharges. Damages or benefits caused by other regulated discharges were determined by comparison to damages by status quo river discharges.

A detailed outline of the calculations made in this study is presented in Appendix II.

Appendix III contains the procedure which should be used in determining the monetary values of any discharges which can be expected to occur from operation of the Keystone Reservoir. Using the data presented in this Appendix, curves can be drawn which will show the rate of damage caused by a range of stream discharges for each month in any year. With these curves and the procedure outlined monetary damages or benefits of any river discharge can be determined.

RESULTS

Damages occurring under natural discharge conditions were used as a base in determining the value of regulated discharges. River discharges which completely abate pollution will eliminate natural damages and are assigned a monetary benefit equal to the damage prevented. Regulated discharges required for each month of the year to prevent tangible damage to the river in excess of that occurring under unregulated discharge conditions, those required for complete pollution abatement, and the monetary benefit of providing the discharges for complete pollution abatement for 1965, 1974, and 1989 with primary treatment of municipal wastes at Tulsa are given in Table 1. "Percent of Time Augmentation is Required" is also shown. These figures for 1975 and 1989 with 85 percent treatment of municipal wastes at Tulsa are given in Table 2. The figures for 1990 with 85 percent treatment of all wastes in the Tulsa area are given in Table 3. Total annual natural damages are shown graphically in Figure 1.

The constant discharges which, if maintained the entire year, would prevent tangible damage to the river beyond that occurring under unregulated discharge conditions are as follows:

Year	Constant Discharge (cfs)		
	Primary Treatment of Municipal Wastes	85 Percent Treatment of Municipal Wastes	85 Percent Treatment of All Wastes
1965	510	---	---
1974	600	---	---
1975	---	405	---
1989	740	505	---
1990	---	---	435

Tangible damages occurring under natural discharge conditions may be simulated by any reservoir operation which results in discharges from which the total of the damages occurring equals the total annual damages under natural conditions. It should be emphasized at this point, however, that rapid and extreme variations in river discharges would cause severe, although intangible, damages to the river. One method of reservoir operation which would simulate natural conditions while conserving possibly the maximum quantity of water would be to release all natural discharges below those required for complete pollution abatement and conserve all discharges above those required for complete pollution abatement. However, the maintenance of constant regulated discharges would provide substantial, though intangible, benefits to the river.

APPENDICES

APPENDIX I. Factors Limiting Industrial Use of Arkansas River Water

Water of the quality encountered in the Arkansas River in the vicinity of Keystone Dam site is unsuitable for most industrial purposes, since its use can result in high repair and maintenance costs. High chlorides in water used for cooling results in corrosion of mild steel surfaces, an action that becomes more severe as operating temperatures increase. As heat exchange surfaces become fouled with products of corrosion, the efficiency of the unit decreases and more water is required to produce the same degree of cooling. At the same time, metal is lost to the extent that replacement of part, or all, of the heat exchangers using such water occurs at more frequent intervlas, with resulting higher operating cost than is the case where lower chloride water is used.

Chlorides are undesirable for another reason. It has been found that stainless steel equipment is subject to failure from stress-corrosion cracking at a much greater frequency if cooling water used in them contains appreciable chlorides. Here, again, temperature plays a major role--the higher the temperature, the lower becomes the permissible chloride concentration. Under some conditions, chloride concentrations of over 80-100 ppm are unacceptable. Relatively high hardness also detracts from the desirability of water for industrial use, since the use without treatment will result in a rapid deposition of scale on heat transfer surfaces. As these deposits build up, the efficiency of the unit for transferring heat decreases. This means that more water must be passed through the exchanger to maintain the same product exit temperature. As scale continues to develop, the amount of water that can be put through

the unit without excessive pressure build-up decreases, and a point is eventually reached when the unit must be taken out of service for cleaning or replacement, a costly step in either case.

The use of high-chloride water for cooling is possible with suitable materials of construction in the heat exchangers such as Admiralty metal or a two-layer system, where a thin sheet of chloride-resistant metal is bonded to a dissimilar metal that resists product attack. In both cases equipment costs are significantly higher than for mild steel construction.

APPENDIX II. Outline of Calculations

A. Determination of organic pollution loadings

1. Collection of data from municipalities and industries
2. Extrapolation of loadings to years under consideration by use of population predictions (See Figure 2.)

B. Determination of stream assimilative capacity

1. Use of basic oxygen-sag equation:

$$D = \frac{L_a}{f-1} \left(10^{-k_1 t} - 10^{-fk_1 t}\right) + D_a\, 10^{-fk_1 t}$$

where:

D = dissolved oxygen deficit (below saturation) at time t

L_a = ultimate B.O.D. (ppm)

D_a = initial dissolved oxygen deficit (ppm)

k_1 = deoxygenation rate constant

k_2 = reoxygenation rate constant

$f = k_2/k_1$

a. Assumptions

1.) $f = 0.2/0.1 = 2.0$

2.) Natural B.O.D. in river = 1.0 ppm (ultimate B.O.D.)

3.) D.O. in river at Tulsa = 80% saturation

4.) Total organic waste discharge from Tulsa-Sand Springs area enters the river at one point

b. Calculation of river discharges required to maintain D.O. levels of 0.0 ppm to 4.0 ppm at temperatures and B.O.D. loadings under consideration

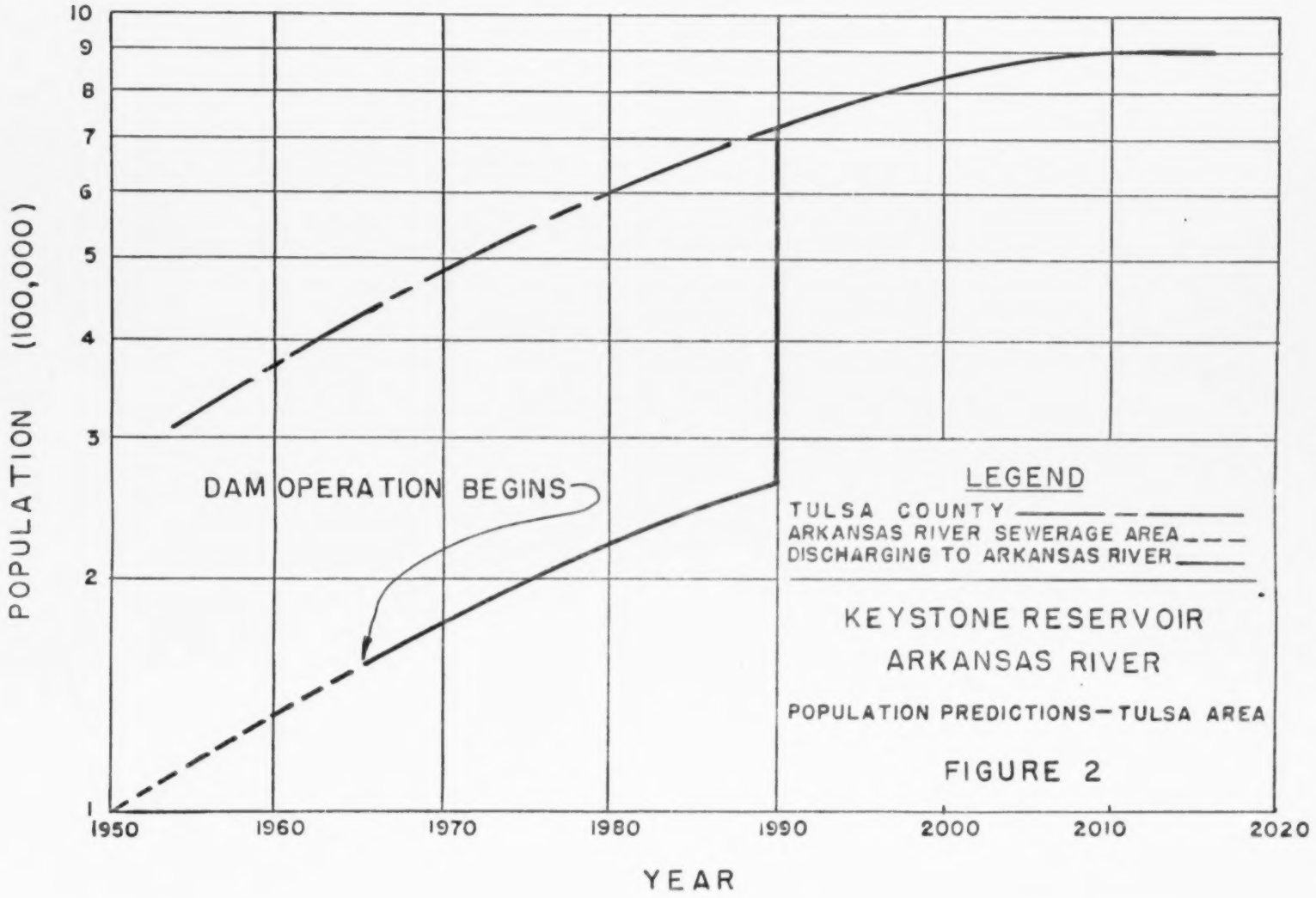

POPULATION (100,000)
10
9
8
7
6
5
4
3
2
1
1950
1960
1970
1980
1990
2000
2010
2020
YEAR
DAM OPERATION BEGINS
LEGEND
TULSA COUNTY
ARKANSAS RIVER SEWERAGE AREA
DISCHARGING TO ARKANSAS RIVER
KEYSTONE RESERVOIR
ARKANSAS RIVER
POPULATION PREDICTIONS—TULSA AREA

FIGURE 2

35a

Sample calculation:

Take 1965 conditions

Take river water temperature = 65°F.

D.O. saturation = 9.48 ppm

Upstream D.O. = (0.80) (9.48 ppm)

= 7.58 ppm

Take D.O. critical = 4.0 ppm

Cooling water for power plant:

Flow = 75 cfs

Temperature = 65°F. + 15°F. = 80°F.

D.O. saturation = 8.11 ppm

D.O. = (0.80) (8.11 ppm) = 6.49 ppm

Wastes:

Temperature = 83°F.

Flow:

23 cfs containing 0.0 ppm D.O.

6 cfs containing 6.3 ppm D.O.

Total flow = 29 cfs

Take a river discharge of 200 cfs

Temperature balance:

(75 cfs)(80°F.) + (29 cfs)(83°F.) + (200 cfs - 75 cfs)

(65°F.) = (229 cfs) X

X = 72.2 °F.

Dissolved oxygen balance:

(75 cfs)(6.49 ppm) + (23 cfs)(0.0 ppm) + (6 cfs)(6.3 ppm) + (200 cfs - 75 cfs)(7.56 ppm) = (229 cfs) $\underline{X}$

$\underline{X}$ = 6.4 ppm, initial D.O.

D. O. saturation @ 72.2°F. = 8.8 ppm

D_a = 8.8 - 6.4 = 2.4 ppm

D_c = 8.8 - 4.0 = 4.8 ppm, critical dissolved oxygen deficit

By calculation of the oxygen-sag equation, L_a = 16.0 ppm

L_a may be obtained either by trial and error methods or from previously developed graphs relating D_a, D_c, and L_a

L_a (waste) = 16.0 ppm - 1.0 ppm = 15.0 ppm

Allowable organic pollution loading = (15.0 ppm)(229 cfs)(5.39) = 18,500 lbs/day B.O.D.

After taking several discharges, allowable B.O.D. loading is plotted versus river discharge. (See Figure 3.) This procedure is repeated for critical D.O. levels of 0.0, 1.0, 2.0, 3.0, and 4.0 ppm at river temperatures of 40°F., 65°F., and 83°F. for 1965, 1974, 1975, 1989, and 1990 conditions.

From points on these graphs, river discharge may be plotted versus critical D.O. for any temperature under consideration when the B.O.D. loading is known. (See Figure 4.)

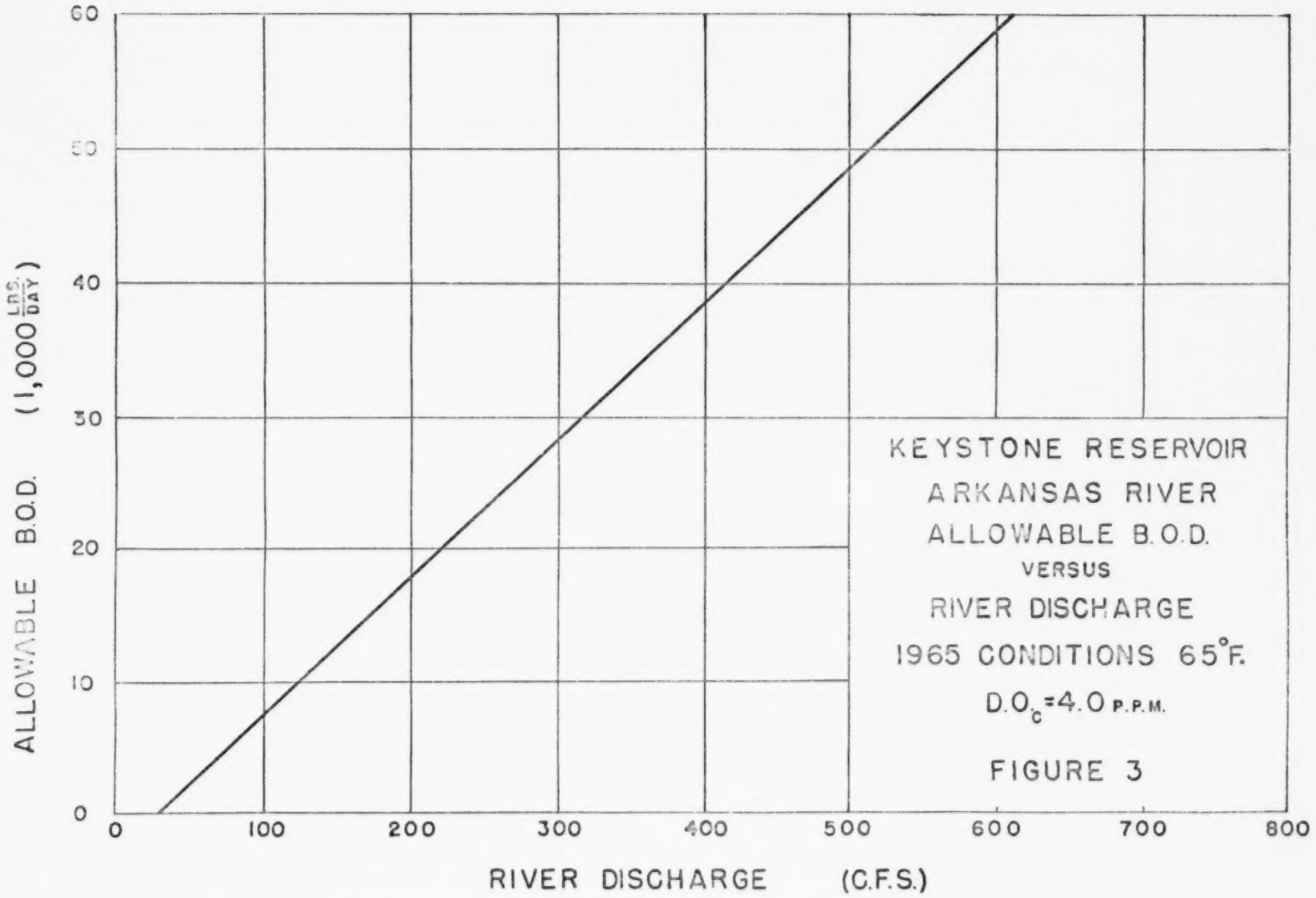
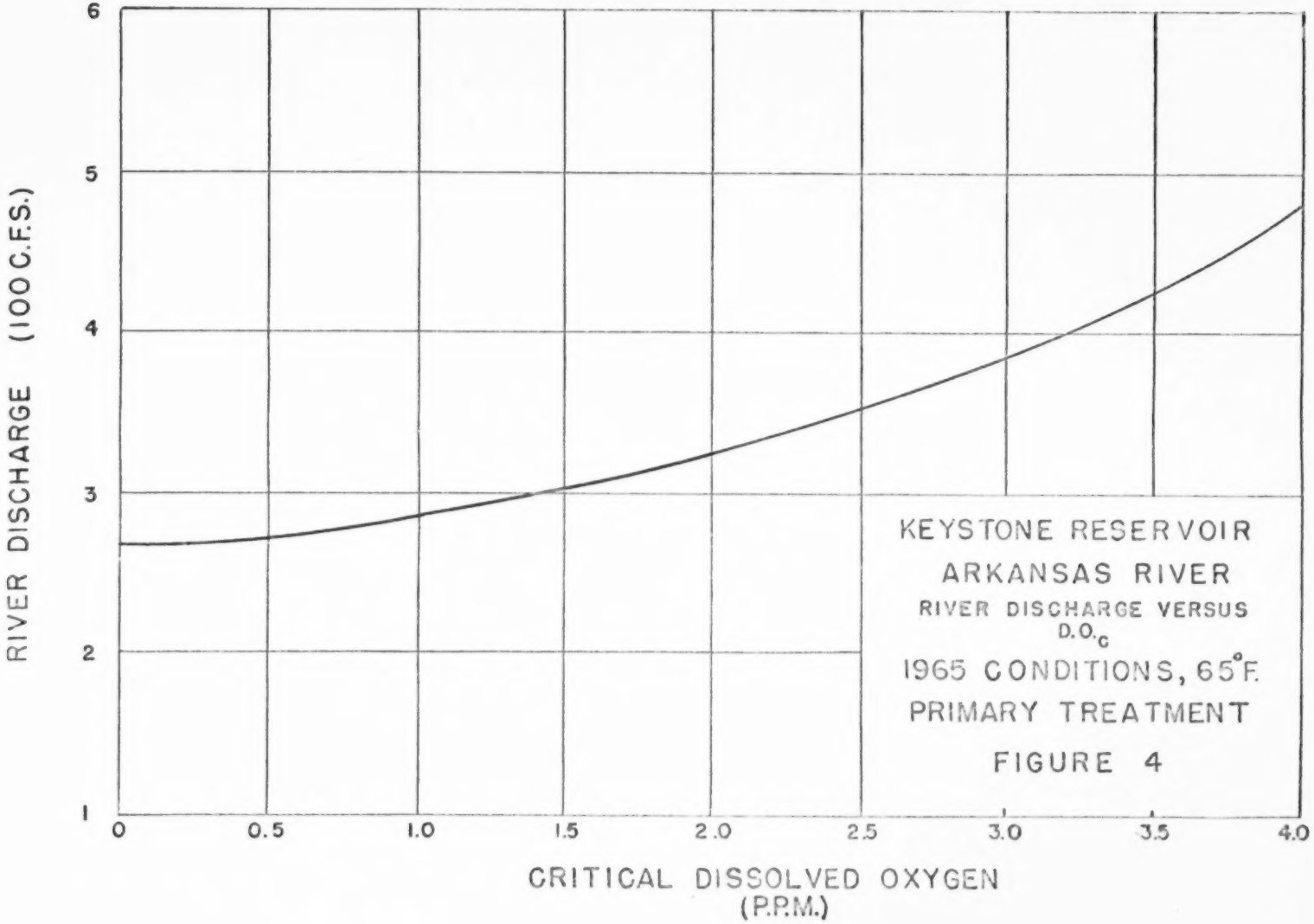

ALLOWABLE B.O.D. (1,000 LBS./DAY)
0
10
20
30
40
50
60
0
100
200
300
400
500
600
700
800
RIVER DISCHARGE (C.F.S.)
KEYSTONE RESERVOIR
ARKANSAS RIVER
ALLOWABLE B.O.D.
VERSUS
RIVER DISCHARGE
1965 CONDITIONS 65°F.
$D.O._c$=4.0 P.P.M.

FIGURE 3

37a


RIVER DISCHARGE (100 C.F.S.)
6
5
4
3
2
1
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
CRITICAL DISSOLVED OXYGEN
(P.P.M.)
KEYSTONE RESERVOIR
ARKANSAS RIVER
RIVER DISCHARGE VERSUS
D.O.c
1965 CONDITIONS, 65°F.
PRIMARY TREATMENT
FIGURE 4

C. Development of river temperature data by month

1. Determination of average temperatures for each month of the year using all past records available - about 10 years (1949-1958)

Average monthly temperatures:

January	40°F.
February	44°F.
March	51°F.
April	61°F.
May	70°F.
June	77°F.
July	80°F.
August	82°F.
September	73°F.
October	64°F.
November	50°F.
December	42°F.

D. Development of discharge frequency data by month

1. Determination of percent occurrence of discharges for each month of the year using all past records available - 20 years (1939-1958)

E. Calculation of frequency of occurrence of D.O. concentrations of 0.0 ppm to 4.0 ppm by month

1. Relating the results of steps B, C, and D

2. Conversion of D.O. concentrations to D.O. deficits below 4.0 ppm D.O.

Sample Calculation:

Take the month of January under 1965 organic pollution loading conditions:

Discharge (cfs)	D.O.c (ppm)	D.O Deficit (below 4.0 ppm D.O.) (ppm)	Frequency of Occurrence (%)
190	0	4	3.5
210	1	3	4.2
240	2	2	5.2
270	3	1	6.4
310	4	0	8.1

F. Determination of cost of treatment plants for 85 percent B.O.D. removal

1. Plant sizes based on waste flows predicted for 25 years in future
   a. Industrial plant
   b. Municipal plant
2. Use of methods presented in Engineering News-Record, October 17, 1957, for estimating sewage treatment plant costs.
3. Amortization @ 4 1/2 % for 25 years
4. Addition of operation and maintenance costs

G. Development of annual damage rate graph

1. Plotting annual damage rate from zero to annual cost of 85% waste treatment plant versus D.O. deficit (below 4.0 ppm D.O.) from 0.0 ppm to 4.0 ppm (See Figure 5.)

H. Calculation of annual damages occurring under natural conditions

1. Using annual damage rate graph and frequency of occurrence (calculated in E., above) for each month of the year.

2. Summation of monthly damages

Sample calculation:

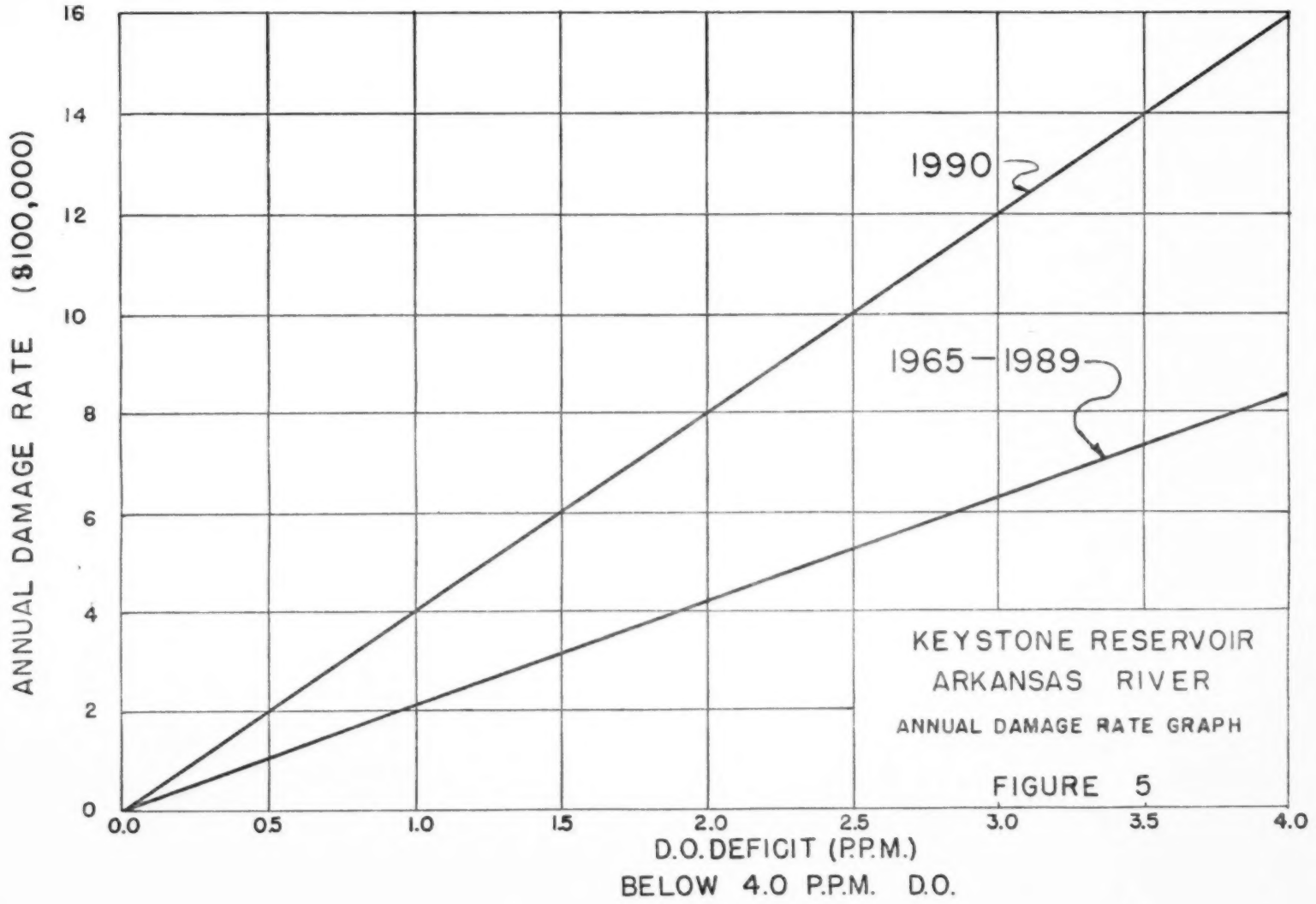
(continuing from step E.)

D.O. Deficit Range (ppm)	Incremental Frequency of Occurrence (%)	Annual Damage Rate ($)	Damage (Based on Annual Rate)($)
4	3.5	$840,000	$29,400
3-4	0.7	735,000	5,140
2-3	1.0	525,000	5,250
1-2	1.2	314,000	3,770
0-1	1.7	104,000	1,770
			$45,330

$\frac{\$45,330}{12 \text{ mos. per yr.}}$ = $3,780 damage for month of January

This procedure is followed for each month, and the results are summed to give the annual damage.

I. Determination of regulated discharges simulating natural conditions (damages)


ANNUAL DAMAGE RATE ($100,000)
16
14
12
10
8
6
4
2
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
D.O. DEFICIT (P.P.M.)
BELOW 4.0 P.P.M. D.O.
1990
1965 – 1989
KEYSTONE RESERVOIR
ARKANSAS RIVER
ANNUAL DAMAGE RATE GRAPH
FIGURE 5

1. Determination of D.O. deficit corresponding to monthly damage rate from annual damage rate chart

2. Determination of discharge required to produce the above D.O. deficit using the oxygen-sag equation as calculated in step B, above, for each month

   Sample calculation:

   (continued from step H.)

   Taking January for 1965 conditions

   $45,330 corresponds to a D.O. deficit of 0.21

   D.O. = 4.00 - 0.21 = 3.79 ppm

   This D.O. corresponds to a discharge of 300 cfs as determined from the graphs prepared in step B.

   This constant discharge of 300 cfs would then result in damages equivalent to natural damages for January. (The no-damage discharge is 310 cfs) This procedure is repeated for each month of the year.

3. Determination of a constant discharge (maintained the entire year) which would result in an annual damage equivalent to that occurring under natural conditions using trial and error methods, assuming discharges and summing monthly damages caused by the discharge assumed

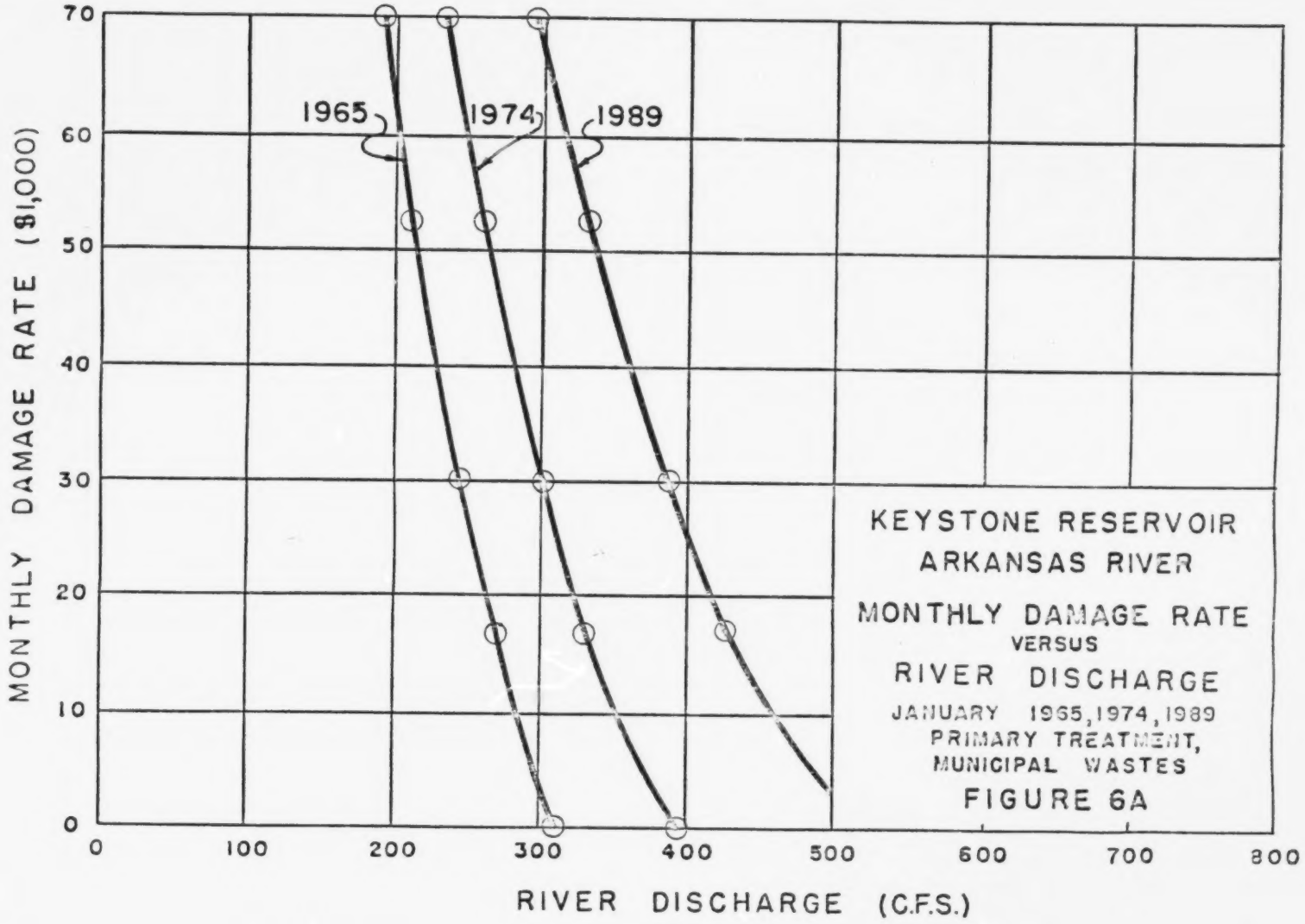
APPENDIX III. Procedure to Be Used to Determine Value of Discharges From the Minimum Experienced Up to the Maximum Discharge Required for Complete Pollution Abatement

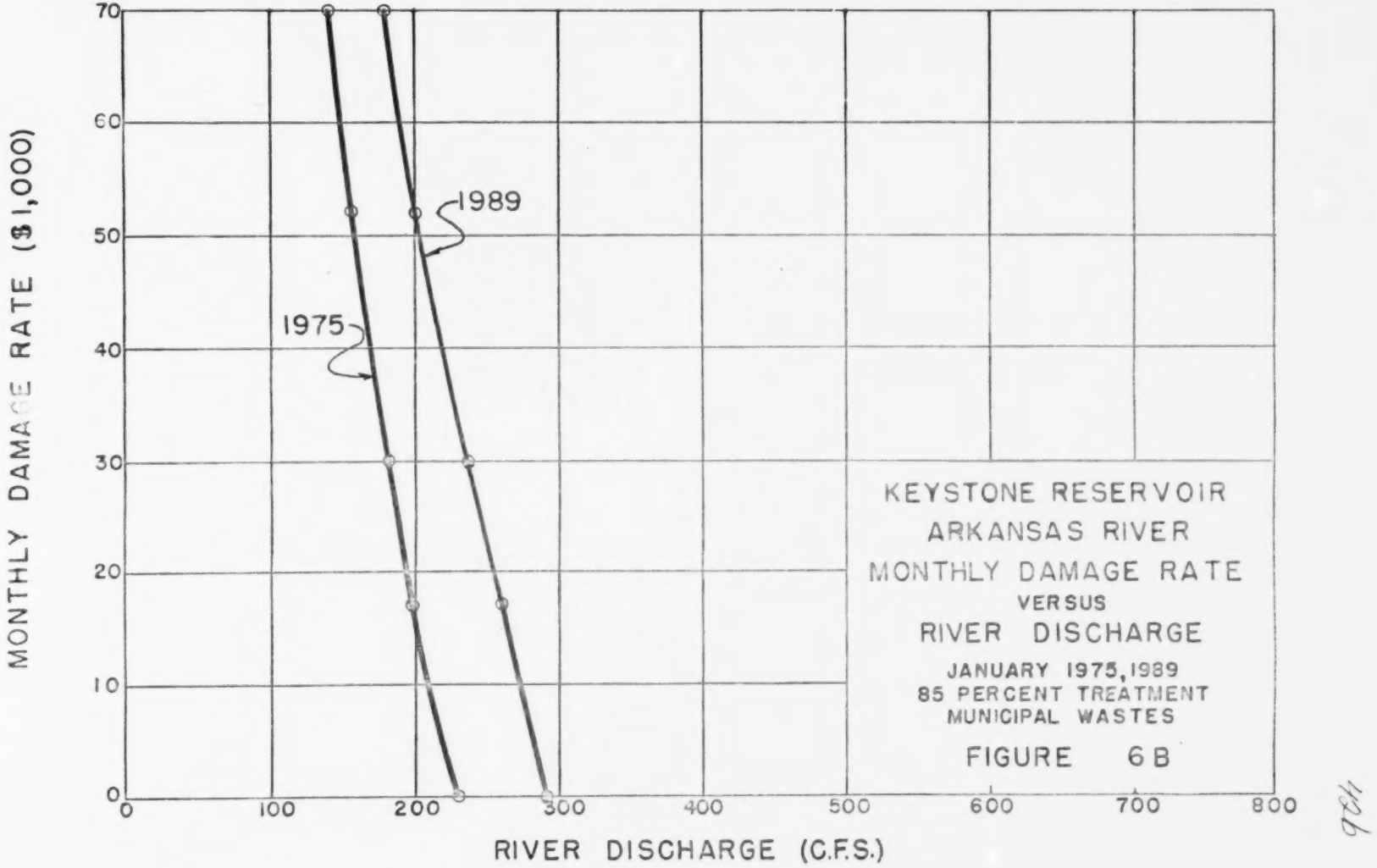
The damages resulting from a range of discharges were determined and are presented in tabular form in Table 4 for the years 1965, 1974, 1975, 1989, and 1990 for the conditions indicated. (See Discussion section for explanation.) These damages are given for each month and are presented as monthly damage rates. Figures 6A, 6B, and 6C are sample curves which were drawn based upon the data presented for January of 1965, 1974, 1975, 1989, and 1990.

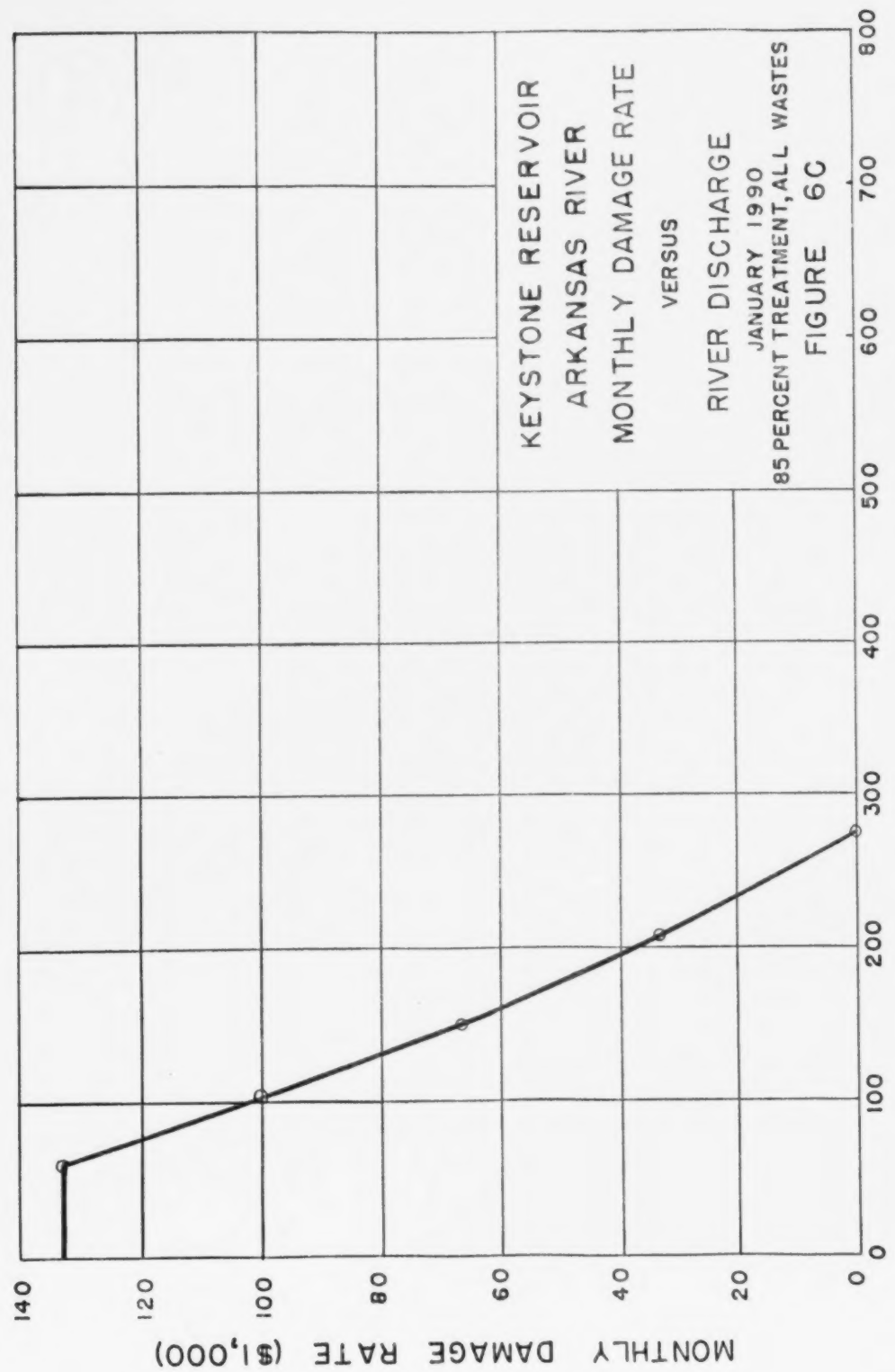
The procedure to be used to determine the value of river discharges resulting from any reservoir operation is as follows:

Given the daily river discharges which may be expected to occur as a result of a certain reservoir operation, damages for each month and year can be determined from the appropriate curve. As this damage is expressed in terms of a rate, the actual damage to the river is determined by multiplying this rate by the percent of occurrence in the month that the given discharge will occur. Repeating this for all the daily discharges expected to occur in each month, the total monthly damage for a given reservoir operation is then determined by summing up the daily damages.

Since damage to the river will occur under natural conditions, the value of any regulated discharge should be determined using this point as a base. This point is given for each month as a river discharge which, if maintained throughout the month, would give the same damage


MONTHLY DAMAGE RATE ($1,000)
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
800
RIVER DISCHARGE (C.F.S.)
1965
1974
1989
KEYSTONE RESERVOIR
ARKANSAS RIVER
MONTHLY DAMAGE RATE
VERSUS
RIVER DISCHARGE
JANUARY 1965, 1974, 1989
PRIMARY TREATMENT,
MUNICIPAL WASTES
FIGURE 6A


MONTHLY DAMAGE RATE ($1,000)
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
800
RIVER DISCHARGE (C.F.S.)
1989
1975
KEYSTONE RESERVOIR
ARKANSAS RIVER
MONTHLY DAMAGE RATE
VERSUS
RIVER DISCHARGE
JANUARY 1975, 1989
85 PERCENT TREATMENT
MUNICIPAL WASTES
FIGURE 6B


KEYSTONE RESERVOIR
ARKANSAS RIVER
MONTHLY DAMAGE RATE
VERSUS
RIVER DISCHARGE
JANUARY 1990
85 PERCENT TREATMENT, ALL WASTES
FIGURE 6C
MONTHLY DAMAGE RATE ($1,000)
RIVER DISCHARGE (C.F.S.)
0
20
40
60
80
100
120
140
0
100
200
300
400
500
600
700
800

as would occur naturally. Regulated discharges which are less than this discharge are considered damages (negative benefits) and regulated discharges greater than this are considered positive benefits.

Table 4. Data to be Used for Plotting River Discharges at Tulsa Versus Monthly Damage Rate

A. Primary Treatment of Municipal Wastes at Tulsa

Month	Monthly Damage Rate	Discharge at Tulsa (cfs) 1965	1974	1989
January	$ 70,000	190	230	295
	52,500	210	260	330
	30,000	240	300	390
	17,300	270	330	425
	0	310	395	520
February	70,000	200	240	300
	52,500	220	275	360
	30,000	250	310	400
	17,300	280	350	455
	0	320	410	545
March	70,000	220	260	320
	52,500	240	295	375
	30,000	275	335	430
	17,300	310	385	495
	0	350	445	590
April	70,000	250	295	360
	52,500	270	335	430
	30,000	310	385	495
	17,300	365	450	580
	0	430	540	705
May	70,000	230	300	405
	52,500	300	370	480
	30,000	350	435	565
	17,300	420	520	675
	0	540	665	850
June	70,000	295	355	445
	52,500	320	400	520
	30,000	380	480	630
	17,300	470	585	760
	0	640	785	1,000

Month	Monthly Damage Rate	Discharge at Tulsa (cfs) 1965	1974	1989
July	$ 70,000	300	365	465
	52,500	330	415	540
	30,000	395	500	655
	17,300	495	615	795
	0	700	845	1,060
August	70,000	305	375	475
	52,500	340	425	550
	30,000	405	515	675
	17,300	510	635	820
	0	730	880	1,110
September	70,000	280	340	425
	52,500	310	385	495
	30,000	360	450	590
	17,300	440	550	710
	0	580	710	910
October	70,000	260	305	375
	52,500	280	345	445
	30,000	325	400	515
	17,300	380	470	610
	0	460	575	750
November	70,000	220	260	320
	52,500	235	295	380
	30,000	270	330	425
	17,300	305	385	490
	0	345	440	580
December	70,000	195	235	300
	52,500	215	270	355
	30,000	245	305	395
	17,300	270	340	445
	0	315	405	535

B. 85 Percent Treatment of Municipal Wastes at Tulsa

Month	Monthly Damage Rate	Discharge at Tulsa (cfs) 1975	1989
January	$ 70,000	140	180
	52,500	160	200
	30,000	180	235
	17,300	200	260
	0	230	290
February	70,000	150	190
	52,500	170	215
	30,000	185	245
	17,300	205	275
	0	240	310
March	70,000	160	210
	52,500	180	235
	30,000	200	265
	17,300	225	305
	0	265	350
April	70,000	180	240
	52,500	200	265
	30,000	225	300
	17,300	270	360
	0	330	425
May	70,000	200	265
	52,500	220	290
	30,000	260	355
	17,300	320	420
	0	400	510
June	70,000	210	285
	52,500	235	310
	30,000	285	380
	17,300	355	470
	0	470	600
July	70,000	220	290
	52,500	245	320
	30,000	300	395
	17,300	375	495
	0	500	640

Month	Monthly Damage Rate	Discharge at Tulsa (cfs) 1975	1989
August	$ 70,000	220	295
	52,500	250	325
	30,000	305	405
	17,300	385	500
	0	525	675
September	70,000	205	270
	52,500	230	300
	30,000	270	360
	17,300	335	445
	0	425	545
October	70,000	190	250
	52,500	210	270
	30,000	235	315
	17,300	285	380
	0	350	450
November	70,000	160	210
	52,500	180	230
	30,000	195	260
	17,300	220	300
	0	260	345
December	70,000	145	185
	52,500	165	205
	30,000	180	240
	17,300	200	270
	0	230	300

C. 85 Percent Treatment of All Wastes in the Tulsa Area

1990

Month	Monthly Damage Rate	Discharge At Tulsa (cfs)
January	$133,300	60
	100,000	110
	66,700	150
	33,300	210
	0	275
February	133,300	65
	100,000	110
	66,700	155
	33,300	220
	0	295
March	133,300	70
	100,000	120
	66,700	165
	33,300	240
	0	330
April	133,300	80
	100,000	125
	66,700	185
	33,300	270
	0	390
May	133,300	90
	100,000	140
	66,700	215
	33,300	310
	0	455
June	133,300	95
	100,000	150
	66,700	240
	33,300	345
	0	525
July	133,300	100
	100,000	155
	66,700	260
	33,300	365
	0	570

Month	Monthly Damage Rate	Discharge At Tulsa (cfs)
August	$133,300	100
	100,000	160
	66,700	270
	33,300	380
	0	600
September	133,300	90
	100,000	140
	66,700	225
	33,300	325
	0	480
October	133,300	85
	100,000	130
	66,700	200
	33,300	285
	0	410
November	133,300	70
	100,000	115
	66,700	165
	33,300	235
	0	325
December	133,300	60
	100,000	110
	66,700	150
	33,300	215
	0	285

Sample Calculation:

For example, take the month of January under 1965 conditions. Suppose that a certain reservoir operation results in the following discharges (taking increments):

Discharge	Frequency of Occurrence
75 cfs	20% of the month
75-190	10%
190-210	3%
210-230	3%
230-250	4%
250-270	4%
270-290	5%
290-310	6%
Greater than 310	45%

From Figure 6A the damage rate for the above increments of discharge can be obtained and then the damage due to these discharges, calculated as follows:

Discharge Range	Monthly Damage Rate	Frequency of Occurrence	Damage
75 cfs	$ 70,000	20%	$14,000
75-190	70,000	10%	7,000
190-210	60,000	3%	1,800
210-230	45,000	3%	1,350
230-250	30,000	4%	1,200
250-270	21,000	4%	840
270-290	12,000	5%	600
290-310	4,000	6%	240
Greater than 310	0	45%	0
			$27,030

From Table 1 the damage to the river in January occurring under natural conditions was given as $3,800. Therefore, the damages above natural damages (negative benefits) due to this reservoir operation will be:

$$\$27,030 - \$3,800 = \$23,200 \text{ (rounded)}$$

Data to be used in plotting river discharges versus monthly damage rates for each month for the years 1965, 1974, 1975, 1989, and 1990 are given in Table 4. Sample curves (Figures 6A, 6B, and 6C) for the month of January which were used in the above example are also presented. These graphs are given as a guide to be used in the development of the curves for the other months in 1965, 1974, 1975, 1989, and 1990. It should be noted that values of river discharges for the intermediate years from 1965 to 1989 will need to be extrapolated from the data presented.

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